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Attorney Docket No. 80168
Date: 24 Jun 2004

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Serial Number	10/779,589
Filing Date	17 February 2004
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Attorney Docket No. 80168
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COMMUNICATION SYSTEM AND METHOD

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT DONALD. H. STEINBRECHER, employee of the United States Government, citizen of the United States of America and resident of Brookline, County of Norfolk, Commonwealth of Massachusetts, has invented certain new and useful improvements entitled as set forth above of which the following is a specification:

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COMMUNICATION SYSTEM AND METHOD

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER RELATED APPLICATIONS

Not applicable.

BACKGROUND OF THE INVENTION

(1) Field Of The Invention

The present invention generally relates to a wireless communication system.

(2) Description of the Related Art

Future approaches to spectrum allocation will likely avoid dedicated spectrum assignments in favor of schemes that allow users to occupy certain frequency bands only when a communications link is established. Spectrum allocation will also favor spectrum-use schemes that use a bandwidth-on-demand architecture so that the bandwidth in use at any specific time is

not larger than necessary to support the data transfer requirement at that time. It is also anticipated that spectrum use schemes capable of searching for temporally free spectrum will be favored over static frequency assignment.

What is needed is a wireless communication scheme that is configured to dynamically utilize available spectrum in an efficient manner in accordance with the future trends and approaches to spectrum allocation discussed in the foregoing description.

SUMMARY OF THE INVENTION

The present invention is directed to a wireless communication system that utilizes the minimum bandwidth necessary to achieve accurate and effective communication. The communication system of the present invention provides a versatile addressing scheme that allows multiple users to communicate over narrow-band channels of a relatively wide-band communication link. The communication system of the present invention is configured to dynamically vary the signal bandwidth between a transmitter and a receiver in an environment where available bandwidth may only exist in non-contiguous small-bandwidth channels or increments. The communication system of the present invention is also configured to (i) combine a set of the small-bandwidth non-contiguous channels to form the required instantaneous signal bandwidth, (ii) use different channels

outside the original set of channels as other channels become available, (iii) use different channels outside the original set of channels as channels within the original set become unavailable and (iv) vary the number of channels utilized to accommodate a time-varying signal-bandwidth requirements needed to effect communication.

The communication system of the present invention utilizes a pair of complementary signal processing schemes for modulation and transmission of information, and for reception and demodulation of the transmitted information. In accordance with the present invention, the communication system utilizes a portion of a wide-band communication link. The first signal processing scheme is implemented in a transmitting system that receives an input sample stream that comprises at least one group of a plurality of sample positions. Each sample position contains a multi-bit Nyquist-rate sample that defines a particular narrow-band digital image. The number of bits in each sample is adjusted by the communication system to provide the accuracy required to achieve accurate and effective communication. Thus, a particular narrow-band digital image is formed by the samples occupying the same sample position within each group of the plurality of sample positions. Each narrow-band digital image is converted to a wide-band digital image and then translated to a narrow-band analog signal. The narrow-band analog signal has a bandwidth that is the same as the bandwidth

of any of the narrow-band channels that form the wide-bandwidth portion of the RF spectrum. The narrow-band analog signal is inputted into a RF (radio frequency) transmitter module that up-converts the narrow-band analog signal to a selected frequency band where the signal is amplified and coupled to a transmitting antenna. The antenna broadcasts the signal over a narrow-band channel of the wide-band communications link. The aforementioned narrow-band channel corresponds to the sample position used to generate the wide-band digital image.

The communications system further comprises circuitry for reception and demodulation of the transmitted signal. The receiving system, which cooperates with a receiving antenna, detects the narrow-band analog signal transmitted over the narrow-band channel. The receiving system includes processing circuitry that translates the received analog signal to a frequency that is suitable for an analog-to-digital conversion process. The analog-to-digital conversion process generates a wide-band composite digital image. The wide-band digital image is then further processed so as to decompose the wide-band digital image into a plurality of narrow-band digital image waveforms. Each narrow-band digital waveform is represented by a plurality of multi-bit Nyquist-rate samples that are assigned to a sample position that is the same as the sample position used to generate the transmitted narrow-band analog signal. Thus, if the original narrow-band digital waveform in the transmitting system

is defined by samples associated with a Kth sample position, then the transmission of the narrow-band analog signal takes place over the Kth narrow-band channel of the communications link, and the received signal is decomposed into a plurality of narrow-band digital images that are matched to the Kth sample position of an output sample stream. Thus, samples associated with the Kth sample position prior to transmission remain associated with the Kth sample position when the received signal is processed and decomposed.

Thus, in one aspect, the present invention is directed to an apparatus for effecting wireless communication, comprising an RF bandwidth partitioner to partition a wide bandwidth portion of the RF spectrum into a plurality of narrow-band channels wherein all of the narrow-band channels have a narrow-band channel bandwidth, a data sample source which provides at least one group of time-domain data samples that are associated with a particular sample position and which define a narrow-band digital image wherein the sample position defines a particular one of the narrow-band channels, a first processor resource to derive a wide-band digital image in the frequency domain from the narrow-band digital image, a digital-to-analog converter to convert the wide-band digital image into a narrow-band analog signal, and a transmitter module to transmit a narrow-band analog signal over a particular one of the narrow-band channels that corresponds to the particular sample position. The transmitter module comprises

an up-converter to transform the narrow-band analog signal to a predetermined RF frequency. The apparatus further includes a monitoring instrumentally to determine which of the narrow-band channels are available for use, and an input for receiving the transmitted narrow-band signal. The apparatus also includes a second processor resource to derive a wide-band digital image signal in the frequency domain from the received signal, a third processor resource to derive a plurality of narrow-band digital images from the wide band digital image wherein each of the plurality of narrow-band digital images are represented by time-domain data samples, and a data storage device to store the time-domain data samples that define the plurality of narrow-band digital images in the sample position that corresponds to the narrow-band channel occupied by the transmitted narrow-band analog signal.

BRIEF DESCRIPTION OF THE DRAWINGS

The figures are for illustration purposes only and are not drawn to scale. The invention itself, however, both as to organization and method of operation, may best be understood by reference to the detailed description which follows taken in conjunction with the accompanying drawings in which:

FIG. 1 is a diagram that illustrates a radio-frequency bandwidth partitioned into a plurality of N equal narrow-band segments.

FIG. 2 is a block diagram of the communications system of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In describing the preferred embodiments of the present invention, reference will be made herein to FIGS. 1 and 2 of the drawings in which like numerals refer to like features of the invention.

As used herein, the terms "narrow-band" and "narrow-bandwidth" are used interchangeably and have the same meaning.

Referring to FIG. 1, the communication system of the present invention utilizes a wide-bandwidth portion 10 of the RF (radio frequency) spectrum. The wide-bandwidth portion 10 has a bandwidth BW. In accordance with the present invention, an RF bandwidth partitioner device or other suitable RF bandwidth processing device is used to partition bandwidth BW into N equal contiguous narrow-band channels or segments 12. Each channel 12 has a bandwidth BN such that N x BN = BW. For example, a wide-bandwidth BW of 15.36 MHz may be partitioned into narrow 30.0 kHz bands. In such an example, N = 512 (i.e. 512 narrow-bandwidth channels). In one embodiment, a software algorithm implemented by a microprocessor or computer is used to generate information defining the bandwidth of each channel 12. In such an embodiment, information defining the desired number of narrow-band channels and the total available bandwidth BW is inputted into the aforementioned microprocessor or computer.

Bandwidth BN is at least the minimum required bandwidth to effect efficient and accurate transmission of data. The lower frequency edge of bandwidth BW is designated as BWL and the higher frequency edge of bandwidth BW is designated by BWH such that BWH = BWL + BW. The narrow-band channels 12 are indexed from BN(1) to BN(N), starting at the lowest frequency narrow-band channel 12a, thereby forming the sequence BN(1), BN(2). . . . BN(N). An arbitrary narrow-band channel is indicated by numeral 12b and designated by BN(k) wherein 0<K<(N+1). The lower frequency edge of BN(k) equals BWL+(K-1)BN and the higher frequency edge of BN(k) equals BWH-(N-k)BN.

The Nyquist sample rate for BW is 2BW and the Nyquist sample rate for BN is 2BN. An analog signal occupying a narrow bandwidth BN may be described by a digital image signal of 2BN samples/second. Similarly, the composite analog signal occupying the wide bandwidth BW may be described by a digital image signal of 2BW samples/second.

Referring to FIG. 2, there is shown a communication system 14 of the present invention. A communication system 14 generally comprises transmitting system 16 and receiving system 18.

Transmitting system 16 generally comprises antenna 20, signal processor 26, digital-to-analog converter 28, and RF transmitter module 30. An input data sample stream 32 defines the digital data or information that is to be transmitted. Sample stream 32 comprises a plurality of groups 34 of N

contiguous individual samples 36. Each sample 36 has a corresponding sample position. For example, sample 36a in each group 34 has a sample position "K". The actual quantity N of samples 36 in each stream 34 is equal to the number N of narrow-band channels such that there is a one-to-one relationship between each sample position and a corresponding narrow-band channel. Thus, the sample having sample position K corresponds to the narrow-band channel BN(K).

Each sample 36 is a multi-bit word. The number of bits in the multi-bit word depends upon the required or desired accuracy. Each sample 36 represents a narrow-band digital image having a bandwidth BN. Each sample 36 has a Nyquist sampling rate of 2BN. In one embodiment, each sample 36 contains a preamble that defines the sample position of that particular sample and the narrow-band channel that is to be used when transmitting signals based on samples extracted from that particular sample position in each group 34.

Signal processor 26 is preferably a digital signal processor ("DSP") such as a digital spectrum encoder. Signal processor 26 includes other processing circuitry such as multi—rate filters and/or commutator circuitry. Processor 26 further comprises electronic circuitry that can effect handling of data in parallel or serial form. Processor 26 also comprises data storage devices such as a random-access-memory (RAM). Input data sample stream 32 is inputted into signal processor 26. Processor 26

synthesizes a wide-bandwidth digital image signal 38 having bandwidth BW. Each digital image signal 38 is formed from the time-domain samples extracted from a particular sample position. For example, processor 26 uses the narrow-band digital images formed by the samples extracted form the Kth sample position of each group 34 to form a wide-bandwidth digital image signal 38 having a sample rate of 2BW samples/second. Signal 38 is a frequency domain signal having a plurality of frequency domain samples wherein each frequency domain sample corresponds to a particular time domain sample. Thus, if there are 512 time-domain samples, there will be 512 frequency domain samples. Therefore, the Kth sample position of the time domain data sample stream, which was inputted into signal processor 26, corresponds to the Kth sample position in the frequency domain sample stream of signal 38.

The rate at which samples 36 are inputted into signal processor 26 can be varied from 2BN samples/second to 2BW samples/second.

However, in a preferred embodiment, signal processor 26 always outputs signal 38 having a sample rate of 2BW samples/second.

Wide-band digital image signal 38 is inputted into digital-to-analog (DAC) converter 28. DAC 28 converts digital image signal 38 into a narrow-band analog signal 40 and then translates the narrow-band analog signal 40 to a bandwidth that matches one

of the narrow-band channels 12. Such translation process utilizes the preamble information, described in the foregoing description, to determine the narrow-bandwidth to which the narrow-band analog signal is translated.

The translated narrow-band analog signal 40 is inputted into an RF (radio frequency) transmitter module 30 that up-converts the narrow-band analog signal to a selected frequency band. The up-converted signal is then amplified and outputted to antenna 20. Antenna 20 broadcasts narrow-band signal 42 over the designated narrow-band channel of wide-bandwidth portion 10 shown in FIG. 1.

Thus, the narrow-band analog signal occupying the narrow-bandwidth channel BN(K), indicated by numeral 12a, is formed by the samples occupying the Kth sample position in each successive group 34 of N samples 36. This relationship is true for all sample positions K in the set $0<K<(N+1)$.

Referring to FIG. 2, signal 42 is received and processed by receiving system 18. Receiving system 18 implements a signal processing method that is the reverse of the signal processing method implemented by transmitting system 16. Receiving system 18 includes antenna 44 which receives transmitted signal 42. Antenna 44 outputs received signal 42 for input into receiver module 50. Receiver module 50 amplifies the received signal and, if necessary, applies particular filtering functions to the received signal. Receiver module 50 also down-converts the

received signal to a frequency suitable for an analog-to-digital conversion process. The output of receiver module 50 is inputted into analog-to-digital converter 52 which outputs a composite wide-band digital image 54 having a sample rate of 2BW. Wide-band digital image 54 is then inputted into signal processor 56. In one embodiment, signal processor module 56 is configured as a digital signal processor such as a digital spectrum decoder. Processor module 56 decodes wide-band digital image 54 into a plurality of narrow-band digital images 58. Each narrow-band digital image 58 is represented by a multi-bit sample having a sample rate of 2BN. The multi-bit samples form an output sample stream 58 that comprises a plurality of groups 60 of N contiguous multi-bit samples 62. Each sample 62 has a corresponding sample position. For example, the sample at the Kth position is indicated by numeral 62a. If the narrow-band analog signal was broadcast over the Kth narrow-band channel BN(K), indicated by numeral 12a, then the resulting narrow-band digital images 58 are decomposed into multi-bit samples in the Kth sample position in each group 60 of samples 62. Thus, the samples occupying the K^{th} sample position in each successive group 60 of samples 62 comprises the digital image of the signal occupying the Kth narrow bandwidth channel BN(k), indicated by numeral 12a, in FIG. 1. This relationship is true for all sample positions K in the set $0<K<(N+1)$.

Signal processor 56 comprises electronic data handling

circuitry, known in the art, for processing data samples in serial and/or parallel format, and data storage devices such as a random-access-memory (RAM).

Thus, the narrow-band digital image comprising the samples occupying the Kth sample position in each successive group 60 of N samples 62 is substantially identical to the narrow-band digital image comprising the samples occupying the Kth sample position in each successive group 34 of N samples 36.

Thus, the communications system and method of the present invention uses only certain narrow-bandwidth channels of a wide-bandwidth portion of the RF spectrum.

The bandwidth between transmitting and receiving systems may be changed in increments of BN by adding digital images with different values of K. If the values of K chosen for different digital images are not consecutive, then the bands of transmission, BN(K), are not contiguous. Thus, the bandwidth between transmitter and receiver can be increased or decreased in increments of BN as necessary for the transfer of information by using un-occupied narrow bands BN(k).

An important feature of the communications system of the present invention is that more than one narrow-band channel 12 can be used to effect communication. Another important feature is that the narrow-band channels utilized need not be contiguous. The communications system of the present invention can also be used to provide system redundancy if necessary. In such a

configuration, the same information is transmitted over a plurality of narrow-band channels 12.

The communications system and method of the present invention can be used with a monitoring or scanning system that monitors the narrow-band channels to determine which of the channels are available and which of the narrow-band channels are in use.

The communications system and method of the present invention can be used to form the basis for other types of communication schemes, e.g. frequency hopping systems, spread spectrum systems, frequency division multiple-access systems, etc. Furthermore, transmitting system 16 and receiving system 18 can be combined to form a transceiver. In such a configuration, a single antenna can be used to transmit and receive signals.

While the present invention has been particularly described, in conjunction with a specific preferred embodiment, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art in light of the foregoing description. It is therefore contemplated that the appended claims will embrace any such alternatives, modifications and variations as falling within the true scope and spirit of the present invention.

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COMMUNICATION SYSTEM AND METHOD

ABSTRACT OF THE DISCLOSURE

A wireless communication system and method. A wide-band analog signal is digitally sampled to form a digital replica. The digital replica is transmitted over a wireless channel using a subset of available narrow-band channels that may or may not be contiguous. Signal parameters may be dynamically adjusted in order to utilize particular portions of the spectrum when those portions of the spectrum are not being used. Channels are selected on a sample by sample basis and multiple channels may be selected simultaneously in order to dynamically increase bandwidth when vacant channels are available. Thus, the data rate is increased on a bandwidth-available basis.

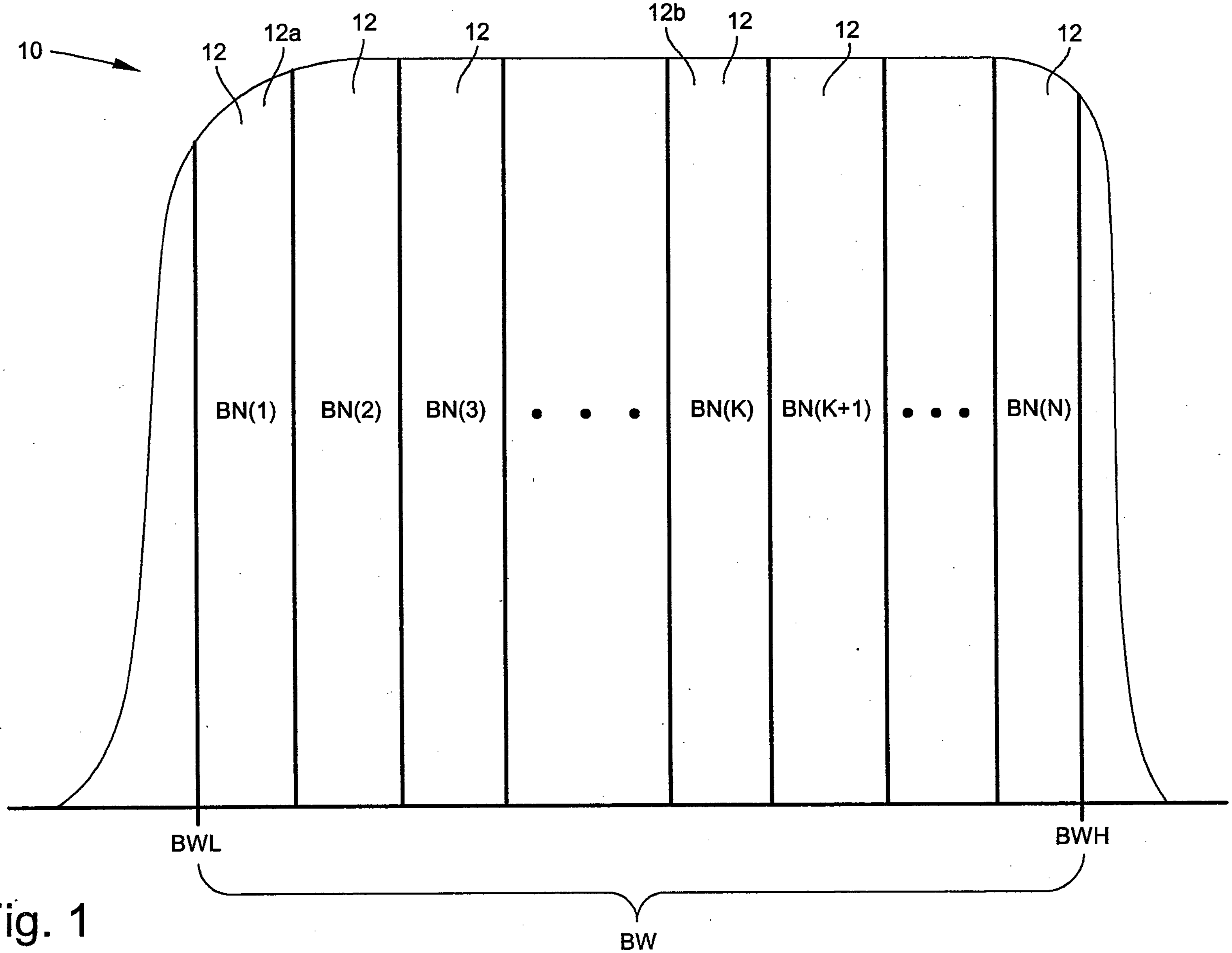
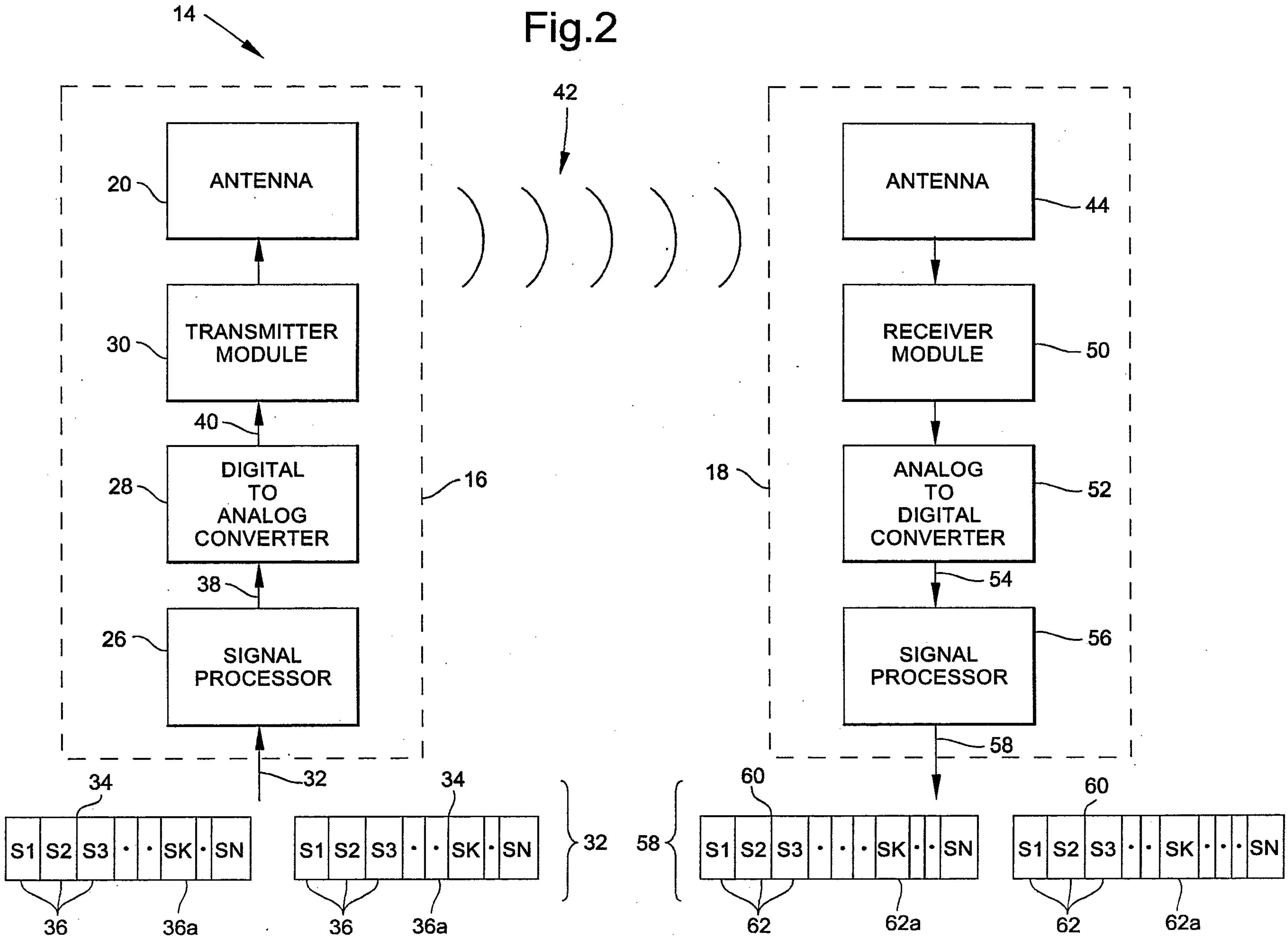


Fig. 1

Fig.2


14
42
ANTENNA
TRANSMITTER MODULE
DIGITAL TO ANALOG CONVERTER
SIGNAL PROCESSOR
20
30
40
28
38
26
16
32
34
S1 S2 S3 SK SN
36
36a
ANTENNA
RECEIVER MODULE
ANALOG TO DIGITAL CONVERTER
SIGNAL PROCESSOR
44
50
52
54
56
58
18
60
62
62a